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INDUSTRIAL INSULATION WITH MINERAL PRODUCTS

BY

OLIVER BOWLES

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

INDUSTRIAL INSULATION WITH MINERAL PRODUCTS [1]

By Oliver Bowles [2]

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INTRODUCTION

The use of fire as a source of heat was the first step from primitive existence toward modern civilization, and heat has performed functions of inestimable importance throughout the ensuing ages. The first commercial steam engine invented in 1698 demonstrated that heat was an important source of power, and heat has since become the motivating force for railroad trains and steamboats as well as for machines in multitudes of factories. Aside from its function of supplying power, heat is an agent of vast importance in chemical reactions and engineering processes.

Because of the high temperature of steam under pressure, losses by radiation from boilers and pipes become excessive unless the radiating surfaces are covered with insulating materials. Insulation is important also for hot-water pipes and many other types of equipment from which heat may radiate. Radiation losses from heated surfaces increase rapidly as the temperature rises, hence special attention should be given to high-temperature operations. Loss of heat from exposed surfaces may entail enormous losses of fuel and power. Therefore, a very important justification for insulation is the money saving involved. The financial benefits that would accrue to industry by the elimination of preventable heat loss through effective insulation have not received the attention their importance justifies.[3] Furtheremore, heat dissipated into the surrounding area may so raise the temperature that much discomfort to workers may ensue or that working conditions may indeed become unbearable.

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[1] The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7263."

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Heat control is another important function of insulation. In many chemical engineering processes close control of temperature and heat flow are required, and where conditions are such that temperature fluctuations are due to the cooling of heated surfaces, adequate insulation of the heat-radiating areas becomes necessary.

Efficient operation, comfortable working conditions, and conservation of fuel are all promoted by judicious use of heat insulators. Fuel conservation is of the utmost importance at this time. War activities consume such vast qualities of fuels of all kinds that every effort should be made to conserve the supply. Every ton of coal, barrel of oil, or cubic foot of gas that can be saved helps to overcome any threatened retardation in munitions output, delay in transportation, or discomfort from the cold in homes, shops and factories. Adequate insulation saves enormous quantities of fuel, and thus speeds the war program.

The Bureau of Mines recently issued a report[4] urging the importance of home insulation as a means of conserving fuel for military use, of reducing the cost of home heating, and of promoting health by maintaining uniform and adequate household temperatures. Conservation of fuel through industrial insulation is of even greater importance owing to the high temperatures maintained in much of the vast equipment used in production of war goods and essential civilian supplies. Should fuel become increasingly scarce and rationing become necessary, the plants less directly connected with the war program probably would suffer curtailment in activity. It is therefore of vital importance that all operators of industrial plants survey their equipment and take immediate steps to save fuel wherever possible. It is the purpose of this paper to cover briefly the sources, properties, and uses of mineral products that may be employed for heat insulation at industrial plants.

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[3] See Industrial Heat and Power Conservation Manual prepared by the Industrial Mineral Wool Institute, 1943, 20 pp.

[4] Bowles, Oliver, Home Insulation With Mineral Products - Conservation of Fuel for War: Bureau of Mines Inf. Circ. 7220, 1942, 11 pp.

PROPERTIES OF INSULATING MATERIALS

Natural minerals or their products used for insulating purposes generally have little inherent heat-insulating capabilities. Their value as insulators depends upon the fact that they possess a porous structure whereby small pockets of air are entrapped, and these air pockets serve as impediments to the transfer of heat. A few minerals like diatomite and pumice possess the desired porous structure as they occur in nature, but most of the mineral insulating materials are processed in one way or another to create the desired air spaces within their structure. One method is to calcine minerals like vermiculite, which, upon application of heat, expand with a honeycomb structure. Another method is to separate the fibers of a naturally fibrous mineral like asbestos so as to produce a fluffy mass with numerous small air spaces between the fibers. A similar fibrous product may be made by blowing a molten silicate into long, fine fibers known as mineral wool, rock wool, glass wool, or slag wool. The fine fibers make a fluffy mass entrapping thousands of air spaces per cubic foot. A porous structure may also be obtained by compacting or binding together extremely fine, light particles of compounds like basic magnesium carbonate.

The insulating value varies with the density of the materials, with the temperature range in which the measurements are made, and with the forms in which the products are fabricated. The numerical value of heat conductivity is not the sole criterion for guidance in selecting an insulating medium, for at times it may be advantageous to use materials of somewhat high conductivity to obtain other desirable properties. For instance, where high temperatures are encountered it may be necessary to use an insulating material that is also a refractory, and, quite commonly, the changes in structure or composition that are found necessary to increase the refractoriness of the product at the same time may reduce its effectiveness as an insulator.

Insulating materials other than those of mineral origin also are used, but their qualities and properties are subjects that fall outside the scope of activities of the Bureau of Mines. The mineral products generally offer certain advantages, chief of which are noninflammability, resistance to the spread of fire, endurance, stability under extreme changes in temperature, and proof against corrosion, mold, and vermin.

The principal mineral insulating materials are mineral wool and related synthetic fibers, asbestos and its products, technical carbonate, vermiculite, diatomite, and porous bricks and aggregates.

MINERAL WOOL

Chemically, mineral wool consists of calcium silicate or mixed silicates of calcium, magnesium, aluminum, or iron. In its primary form it consists of fine, interlaced fibers having the appearance of loose wool or cottom. Mineral wool is a generic term covering a number of similar fibrous products differentiated chiefly by the raw materials from which they are made. "Rock wool" is made from natural rock (a calcareous shale, sometimes termed "wool rock") or from combinations of various natural minerals or rocks, such as limestone and shale. "Slag wool" is made from iron, copper, or lead blast-furnace slag alone or mixed with fluxing materials. "Glass wool" is made from silica sand, soda ash, and limestone with or without scrap glass or other materials.

Mineral wool is made by first melting the properly proportioned silicates in a short cupola furnace. Coke is the fuel generally used. The molten material issues from a small hole at the bottom of the furnace and is blown into fibers by a jet of air or steam at 80 to 100 pounds pressure. When removed from the blower room, the fiber is processed and made ready for use in loose wool form or for manufacture into mineral-wool products.

Mineral wool has certain desirable properties that favor its use as an industrial insulating product. One is its low thermal conductivity - 0.27[5] at 90° F. mean temperature. It also has the ability to withstand high temperatures, as its melting point is 1,200° to 1,800° F., depending upon the type of wool and the form in which it is fabricated. Its silicate composition renders it resistent to chemical action. The raw materials used are noncritical, which is an additional advantage at this time.

The wool is applied to industrial equipment in various forms for which standard specifications have been formulated.[6] Loose wool may be used for filling spaces where bulk insulation is required. Granulated wool in the form of pellets approximately half an inch in size may be used as a heat-insulating space filler, for instance in the walls of railroad cars. Blankets ranging in thickness from 1 to 6 inches are used for covering furnace and boiler walls, annealing and baking ovens, retorts, and other types of equipment having flat or moderately curved surfaces. Blankets for such uses are made of loose wool that may or may not be treated with binders. They are commonly confined between wire mesh and metal lath or combinations thereof and are in various rectangular sizes. Felted blankets used in cold-storage areas and for fireproofing may also be treated with binders but are rarely confined between metal fabrics.

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[5] British thermal units transmitted per hour per square foot of material 1 inch thick, per °F. difference in temperature of the two faces.

[6] National Bureau of Standards, Mineral Wool; Loose, Granulated, Or Felted Form, in Low-Temperature Installations: Commercial Standard CS105-43. (For sale by Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 5 cents.)

National Bureau of Standards, Mineral Wool; Blankets, Blocks, Insulating Cement, and Pipe Covering For Heated Industrial Equipment: Proposed Commercial Standard. (Available upon request to National Bureau of Standards, Department of Commerce, Washington 25, D. C.)

Mineral-wool block is made by treating the wool in loose form with binders and compressing it to desired thickness and density. It assumes a rigid but resilient form and is notably resistant to cracking under vibration. Blocks are applied on equipment having an operating temperature up to 1,800° F. and are easily cut to fit irregular surfaces. Common types of equipment on which they are used are boiler walls, ovens, hot-air ducts, kilns, annealing pits, and heat-treating furnaces.

Loose wool may be made into boards, which, like blocks, are treated with binders and are compressed to standard thickness and density. When enclosed in a casing of odorless asphalt composition, they are used to insulate cold-storage areas.

These and other types of compressed blocks and sheets are applied to insulation of oil heaters, electric and gas ovens, hot water-storage tanks, steam-turbine casings, steam boilers, oil stills, oil- and gasoline-storage tanks, dairy trucks, stoves, furnaces, glass tanks, refrigerators, and water coolers. They are also employed in many other ways on ships, in munition plants, and in innumerable civilian establishments. Refractory binders are used in making high-temperature insulation blocks.

Pipe coverings are of two types - blanket and molded. The blanket type consists of felting loose mineral wool to desired thickness and density then encasing it between metal fabrics, the use of which obviates the need of binders, thus permitting the retension of its maximum thermal efficiency. Molded-type pipe covering is made of granulated mineral wool mixed with suitable binders, moistened, then shaped and dried in molds to fit standard pipe sizes. Glass wool treated with resinous binders is also formed into pipe coverings by molding and shaping operations. For pipes exposed to the weather, the coverings may be provided with an exterior waterproof coating of an asphalt-base mastic. Coverings of one form or another are used extensively in insulating high-pressure steam, hot-oil, molten-sulfur, hot-water, and many other types of furnace, boiler, and transmission pipes. Steam pipes are prolific sources of heat waste, and their proper insulation is an outstanding means of conserving fuel. In the low-temperature field, both types of pipe covering are used to prevent freezing of water pipes and absorption of heat by such products as brine, ammonia, and freon.

Another important product is mineral-wool cement, which consists of granulated or nodulated wool mixed with long-fiber asbestos and bonded with a suitable binder such as bentonite or plastic fire clay. Before application, it is mixed with water to bring it to proper mortar consistency. It may be applied to either hot or cold surfaces of furnace or boiler walls and can readily be applied even though the surfaces may be quite irregular. When dried, it forms a monolithic coating. It has the advantage, therefore, of eliminating the escape of heat through joints that would be present if built-up blocks or other individual insulation units were used. It is also used for filling joints between insulating blocks. It is claimed that such cements weigh about 35 pounds per cubic foot and have a thermal conductivity of about 0.6. Insulating cements are used at times as coatings over mineral-wool blankets to protect them from the weather. The layer of cement, in turn, is coated with an asphaltic weather-proofing compound.

Mineral wool is attaining increasing importance in industrial insulation. A survey conducted recently by the Bureau of Mines furnishes, for the first time, definite statistics for mineral wool used for industrial insulation. Sales in 1942 reported by 30 companies totaled 133,930 short tons valued at $16,740,501 exclusive of pipe coverings, which could not be expressed as tons because pipes are of many sizes and data were not obtainable in enough detail to segregate the coverings by size. Sales of mineral-wool pipe covering in 1942 totaled 5,582,217 lineal feet valued at $1,149,463.

ASBESTOS

The term "asbestos" is applied to a group of minerals possessing a fibrous structure. The fibers may be separated, giving a soft fluffy mass with many minute air spaces between the individual strands. As an insulating material, asbestos may be used alone or it may be compounded with other products. The well-known 85 percent magnesia will be discussed in a later section devoted to magnesia insulation.

There are several varieties of asbestos differing from each other in physical and chemical properties. The principal asbestos of commerce is chrysotile, the fibers of which are generally strong and flexible. Blue asbestos (crocidolite), mined in Africa and Australia, and amosite, mined only in Africa, also possess strong fibers suitable for spinning and many other uses. They are varieties of amphibole asbestos, but the principal

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amphibole found in the United States is the variety anthophyllite, which consists of weak fibers that may be formed into products having good insulating properties suitable for use where strength is not a requisite. Not more than a few hundred tons of anthophyllite are used annually in the United States. Chrysotile asbestos is mined in Vermont and Arizona, but our principal supplies are imported from Canada and Africa.

Asbestos paper is an important insulating product. Chrysotile asbestos of paper-stock grade is agitated with water to form a slurry, to which starch, flour, and sodium silicate may be added. It is fabricated on a paper machine similar to that used in the manufacture of paper from rags or wood pulp. The paper is dried on hot cylinders and wound in rolls.

A widely used paper product is air-cell pipe covering. The first step in manufacture is to form crimped paper by passing the flat paper between corrugated rolls. The tips of the corrugations are then coated with sodium silicate, and a flat sheet is added. This forms a flexible insulation about one-fourth inch thick. It is used for insulating hot air-heater or furnace pipes and for making air-cell sectional pipe covering. Two-ply, three-ply, or thicker coverings may be made, depending upon the number of layers employed. The air spaces between the corrugations furnish the insulation. Asbestos air-cell board is made by superimposing layers of air-cell corrugated paper, with the corrugations of alternate layers at right angles to each other. It is used for insulating and fire-proofing walls and ceilings.

Flat asbestos paper is used in lining gas stoves, ovens, ranges, for wrapping around hot air-furnace pipes, and in numerous other ways, but its uses in this form are primarily for fire-proofing rather than for insulation.

Millboard is another asbestos product used for industrial insulation. It is generally classed with asbestos paper, because it is manufactured by the same general process. It is simply a thick paper; it bears the same relation to asbestos paper that cardboard bears to wrapping paper. The board is usually built up on rectangular screens rather than on drums. It is used for fire screens and partitions, for protecting and insulating walls and ceilings, and for lining furnaces, stoves, and grates.

A form of asbestos tape consists of strands of asbestos enclosed loosely in a sheath of woven asbestos. It is wound spirally on pipes, particularly on locomotive and car piping, and is adapted to fit curves and elbows as well as straight pipe. It is held in place with wire clamps and is easily removable.

The longer grades of chrysotile asbestos may be spun into yarn and woven into cloth, and asbestos woven fabrics have many uses in industrial insulation. For effective fire-fighting, asbestos clothing in whole or in part has become essential. For some purposes complete suits are required; for others, leggings, aprons, breast protectors, helmets, or gloves may be sufficient. Asbestos gloves or mittens are useful insulators where workmen must handle hot articles, as in glass works, foundries, smelters, and arsenals.

Long-fiber amosite asbestos from Africa is felted into blankets of exceptionally light weight, which are preferred for certain special uses on ships. Long-fiber amosite has special qualities of moisture and corrosion resistance that adapt it for certain types of insulation for underground steam pipes. Short-fiber amosite together with certain binders is used for making a block insulation weighing 11 to 14 pounds per cubit foot and having a thermal conductivity ranging from 0.38 at a mean temperature of 121° F. to 0.44 at a mean temperature of 382° F. It is used extensively by the Navy. Short-fiber amosite is also used for making a product known as "spraybestos." A binder such as starch is added, and the slurry is sprayed on walls or other surfaces in successive layers. It serves both for fire-proofing and insulation.

A special processed form of alumina reinforced with asbestos fibers is compressed into blocks and bricks, which are used to line ovens, kilns, and furnaces of all kinds, in which temperatures range from 500° to 2,500° F. Various other forms of asbestos-block insulation are on the market.

Asbestos cement consists of short-fiber asbestos mixed with binding materials such as plastic clay, magnesia, or silica. Water is added to form a paste, and the product is applied with a trowel to furnaces, boilers, and other surfaces from which heat may escape. An asbestos-cement coating is sometimes applied to the surface of wallboard for both heat insulation and fireproofing.

Asbestos appliances that may be classed with industrial insulators include table mats, stove mats, and pot holders.

The following statistics, compiled by the Bureau of the Census, indicate the volume of trade in some of the asbestos insulating products. Data for years later than 1939 are not available.

Certain asbestos insulating materials manufactured in the United States, 1935, 1937, and 1939

Product	1935		1937	
	Quantity	Value	Quantity	Value
Pipe and boiler covering air-cell .... feet	22,804,499	$1,818,833	31,132,243	$2,011,317
Pipe and boiler covering other than air-cell ..... do.	7,530,951	1,608,149	16,189,378	2,281,338
Insulating cements.....pounds	28,486,049	423,370	39,698,757	681,380
Table mats and protectors...	700,082	371,933	898,043	456,873
Other products[1]		4,560,772		7,556,624

Product	1939	
	Quantity	Value
Pipe and boiler covering air-cell .... feet	37,347,901	$2,914,106
Pipe and boiler covering other than air-cell...... do.	12,417,543	2,090,148
Insulating cements .. pounds	52,846,933	766,490
Table mats and protectors...	1,578,865	592,895
Other products[1]		14,216,345

[1] Includes asbestos paper, millboard, and miscellaneous products for the year 1935; includes, in order of value, conduits and ducts (asbestos compositions), molded clutch facings, paper, and high-temperature cements for 1937 and 1939.

BASIC MAGNESIUM CARBONATE

One of the best-known insulators consists of a good grade of asbestos - chrysotile, blue or amosite - which constitutes 15 percent by weight of the product together with 85 percent of so-called magnesia. This term is really a misnomer, because magnesia is magnesium oxide (MgO), whereas the insulating product is a basic magnesium carbonate. It is generally obtained by treating dolomite (calcium-magnesium carbonate) by the Pattinson process, whereby it is calcined, slaked and suspended in water, recarbonated under pressure, and the insoluble calcium carbonate separated from the solution of magnesium bicarbonate by filtering. When the filtrate is boiled, a relatively insoluble basic magnesium carbonate, commonly called "technical carbonate," is precipitated. It may also be obtained by appropriate treatment of magnesite, brines, or salt-works bitterns.

This fine-grained, light product, mixed with the asbestos fiber is thoroughly agitated in water and filter-pressed into cakes, which are

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dried for 3 days in steam-heated kilns. The blocks are then trimmed, cut in lengths, and bored to form hollow cylinders. These are sawed lengthwise, and the half-cylinder sections are rolled in pairs in glued canvas jackets. For ordinary use, the walls have a maximum thickness of about 2-1/2-inches.

This type of pipe covering has a weight of about 19 pounds per cubic foot and a thermal conductivity ranging from 0.42 at a mean temperature of 117° F. to 0.45 at a mean temperature of 327° F. It is generally classed as high-temperature insulation, as it will bear temperatures up to 600° F. without detrimental physical effects.

Eighty-five percent magnesia is also made into blocks of various sizes and thicknesses. These are applied to boilers, cylinders, tanks, domes, and other large radiating surfaces. Locomotive-boiler lagging is a well-known form. Plastic 85 percent magnesia cement is used in filling the joints and for troweling the outer surface. The blocks are held firmly in place with wires and T hooks.

According to Bureau of Mines records, the following quantities of dolomite were used in the manufacture of basic magnesium carbonate during recent years:

Dolomite sold or used for basic magnesium carbonate, 1933-42

Year	Short tons	Year	Short tons
1933	83,640	1938	62,540
1934	83,970	1939	89,390
1935	96,810	1940	80,210
1936	126,260	1941	105,670
1937	96,730	1942	117,650

The size of the basic magnesium carbonate industry is indicated by the following figures, compiled by the Bureau of the Census. Data for years later than 1939 are not available.

Basic magnesium carbonate products manufactured in the United States 1935, 1937, 1939

Product	1935		1937	
	Quality	Value	Quality	Value
Pipe and boiler covering, 85 percent magnesia .....feet	12,153,486	$1,781,904	22,325,857	$3,133,537
Molded blocks, 85 percent magnesia .... board feet	13,747,150	1,072,823	21,384,746	1,952,803
Cement, 85 percent magnesia .... pounds	(1/)	(1/)	3,474,907	153,304

Product	1939	
	Quality	Value
Pipe and boiler covering, 85 percent magnesia .... feet	18,387,492	$3,331,957
Molded blocks, 85 percent magnesia .... board feet	20,077,451	2,020,778
Cement, 85 percent magnesia .... pounds	2,098,081	117,611

1/ Data not available.

VERMICULITE

Vermiculite received its name from its peculiar property of expanding and unfolding into wormlike forms when heated. The name is applied to a group of micaceous minerals that are alteration products of biotite, phlogopite, and other varieties of mica. Its most pronounced characteristic is its extraordinary expansion when heated; the volume may increase up to 16 times the original. The porous nature of the expanded mineral makes it an ideal heat insulator. It is mined chiefly in Montana but also in Wyoming and North Carolina, and it is processed in plants situated at various convenient marketing centers.

Mining is by open-pit methods. The crushed, screened, and dried vermiculite may be exfoliated in an inclined-shaft furnace in which batteries of burners at 6-foot intervals calcine it. Calcination is also accomplished in revolving tubes indirectly fired with oil. In North Carolina a modified vertical shaft furnace is used. The falling particles pass over staggered baffles and are calcined at a temperature of about 2,000° F. An oil-fired burner supplies the heat.

The insulating value of vermiculite depends upon the degree of exfoliation that takes place when it is calcined. When fully exfoliated, it has a thermal conductivity of about 0.48 and a weight per cubic foot of 6 to 8 pounds.

The principal uses are as a lightweight aggregate in concrete and as loose house fill. Vermiculite concrete may be poured in place or it may take the form of blocks or precast slabs. It is primarily a building material, but it also has industrial uses: for instance, in insulating floors, walls, or roofs of cold-storage rooms, and for lining cracking units in refineries, where the vermiculite blocks serve as both refractories and insulators. A concrete consisting of 1 part portland cement and 8 parts vermiculite may have a weight as low as 26 pounds per cubic foot and a thermal conductivity of 0.76 at a mean temperature of 50° to 90° F. An increase in the proportion of cement increases strength and weight but lowers insulating value. Tests recorded by the University of North Carolina[7] show that thermal conductivity ranges from 1.88 for a 1:1 mix to 0.92 for a 1:5 mix at a temperature of 99° F.

Vermiculite in the form of loose pellets is used to fill spaces, providing insulation on open-hearth furnace roofs and in bake ovens, driers, water heaters, and various other types of equipment. When consolidated with a binder into sheets and blocks, it is used extensively to insulate fireless cookers, incubators, ovens, water coolers, refrigerators, refrigerator and passenger cars, airplanes, commercial ice plants, or other apparatus that must have protection from loss or penetration of heat. Various bonding agents are used in making insulating blocks or bricks. Casein may be used for low-temperature and sodium silicate for high-temperature applications. Other binders are bentonite, fire clay, gypsum, and either amphibole or chrysotile asbestos. One important use is the manufacture of prefabricated pipe coverings, which have a thermal conductivity of about 0.65 at a mean temperature of 50° to 90° F.

Insulating bricks are of three types. One is a very lightweight brick that has low conductivity but also low structural strength. Such bricks are used in places where effective insulation is needed and where they are not subject to burden or structural strain. The weight of a standard brick is 24 ounces and its thermal conductivity is about 0.7. Vermiculite bricks for construction of walls or for use in other places where resistance to impact or load are involved must have additional binders to give them the necessary strength. As strength is increased, insulating value is sacrificed to some extent, because the binders increase heat conductivity. The weight of a standard high-strength brick is 33 ounces, and the thermal conductivity is about 0.80. The third type is for high-temperature insulation. This specially made brick, having a suitable refractory binder, is said to have high insulating value and to be adaptable for furnace use where temperatures range as high as 2,000° F.

7/ Scholes, W. A., Greaves-Walker, A. F., Todd, E. R., and Cox, D. F., The Development of Light-Weight Concretes from North Carolina Vermiculites: Univ. of North Carolina Eng. Exp. Sta. Bull. 24, 1942, p. 60.

Insulating cements made of expanded vermiculite and suitable binders are plastic, adhesive, and of low shrinkage. They are used for pipe and boiler covering and to fill spaces between insulating blocks. A special high-temperature cement is designed for insulating open-hearth steel furnaces. It is said to have a thermal conductivity of 0.65, a dry weight of 21 pounds per cubic foot, and to be capable of withstanding temperatures up to 3,200° F.

A wide variety of vermiculite plasters are available for both sound and heat insulation.

Statistics on vermiculite are not given in sufficient detail to show the quantities used specifically for industrial insulation, but total sales, as given in the following table compiled by the Bureau of Mines, may be of interest.

Vermiculite sold or used by producers in the United States, 1924-42

Year	Short tons	Value	Year	Short tons	Value
1924	2	$68	1934	4,746	$56,965
1925	102	2,813	1935	7,068	88,445
1926	150	3,750	1936	16,933	185,787
1927	51	1,318	1937	26,556	260,664
1928	1,006	38,118	1938	20,700	192,000
1929	982	24,483	1939	21,174	174,587
1930	831	13,682	1940	22,299	137,698
1931	1,256	24,758	1941	23,438	125,444
1932	1,643	16,950	1942	57,848	319,931
1933	2,247	21,993			

The values given in the foregoing table are those of raw vermiculite, but the mineral does not reach the consuming market in raw form. Assuming an average value of $70 a ton for vermiculite when exfoliated and otherwise prepared for market, the value of sales in 1942 would exceed $4,000,000.

DIATOMITE

Diatomite, known also as tripolite, kieselguhr, and diatomaceous earth, is of organic origin, consisting essentially of the fossil remains of microscopic aquatic plants known as diatoms. The siliceous shells or envelopes of these minute organisms possess, as seen under high magnification, a multitude of skeletal, cellular forms, and these furnish the porous structure that is an essential element of heat insulators. Diatoms thrived both in oceans and lakes, hence both marine and fresh-water deposits occur. Pure diatomite has a low density and occurs in porous, chalklike masses, the color of which ranges from white or light gray to buff or green.

Extensive deposits of pure material occur in California. Deposits are numerous also in Oregon, Washington, Nevada, Arizona, Utah, Idaho, New Mexico, Maryland, Virginia, New York, New Hampshire, and Florida. Many of the eastern beds are contaminated with silt or clay.

Open-pit quarry methods employing power shovels and dragline hoists are commonly used. In some locations, underground methods involving simple shrinkage or room-and-pillar stoping are followed. Because of its porous nature, the water content of the freshly mined product may range from 10 to 65 percent, hence drying is an important step in preparation.

Diatomite products may be classed as brick or block, crushed aggregate, and fine powders. The powder weighs about 10.6 pounds per cubic foot, and the blocks about 28 pounds. The thermal conductivity of the powder is 0.3 to 0.5 and of the blocks 0.58.

Diatomite brick are of two types - sawed and pressed or molded. The natural brick are cut in the quarry like building stone. They are cut from the solid bed, slightly oversize, by means of specially constructed saws. The brick are than dried, trimmed by grinders, and some of them are packed in cartons for use in their natural state. Others are calcined in kilns before they are packed for shipment. Natural diatomite brick are said to have a thermal conductivity of 1.1 at 1,203° C.

There are three general varieties of pressed brick: First, the ordinary brick, which is made from a high-quality diatomite. Powdered diatomite is moistened with water to a paste, pressed into shape, dried, and fired to the desired temperature. Sometimes bonding materials such as lime or clay are used.

The second class is made from a heavier form of diatomite. The density is reduced, however, by adding organic matter such as ground cork, which burns away during calcination, thus increasing the porosity. One brick of this type, said to have a thermal conductivity of 0.82, is modified to adapt it to different temperatures ranging from 1,600° to 2,500° F.

The third type is designed especially for high-temperature work, and for this silica in the form of tridymite is preferred because it undergoes little expansion or contraction with temperature changes. Diatomite consists essentially of opalescent silica the water of which is driven off during the early stages of calcination. The resulting silica (SiO_2) is trimorphous, the different forms being stable under different conditions of temperature. At 870° C. it changes to tridymite. At 1,470° C.

tridymite passes over into cristobalite, which is undesirable in a refractory brick because it contracts or expands appreciably with only slight changes in temperature, which results in spalling or cracking. To obtain the tridymite form the diatomite is calcined at a temperature between 870° and 1,470° C. The calcined product is then shaped into brick and recalcined. Binders consisting of refractory clay or lime may be added.

Pipe coverings are made by adding suitable binders such as asbestos fiber, lime, or magnesia to pulverized diatomite, molding the shapes under pressure, and drying. To make cast compositions, diatomite aggregate or powder is mixed with a hydraulic bonding agent such as portland cement or calcined gypsum. Aggregate for this and other uses is prepared by ordinary methods of crushing, screening, and sizing.

Pulverized diatomite may be used for insulation in the form of loose fill. To make the pulverized product, dried diatomite is first passed through crushers or toothed rolls. It is then reduced to a powder, usually in some form of hammer mill. The object is to free the individual diatom shells from each other but not to crush them unnecessarily, which would tend to reduce their porosity. The coarser sizes are screened out for packing, and the finer material is graded by size with air separators.

Pulverized diatomite with addition of asbestos fiber or other bonding agents may be mixed with water to form a mortar or cement suitable for furnace insulation, for filling joints, or for covering irregular surfaces.

Diatomite products are well adapted for high-temperature insulation in ovens, cookers, furnaces, and kilns, also for low-temperature insulation to prevent the passage of heat to cold-storage and refrigerator plants, ice houses, and coolers. Brick are used extensively for lining furnaces, in which they are usually placed behind the firebrick facing and are backed by ordinary brick. Thus sandwiched in, they are effective in cutting down loss of heat. Sometimes the intermediate space is filled with loose diatomite powder instead of shaped bricks or blocks.

The industrial uses of diatomite include insulation of boilers, steam pipes, stills, retorts, oil lines, hot-blast stoves, byproduct coke ovens, bake ovens, all kinds of furnaces, rotary and shaft kilns used by the cement and lime industries, foundry ladles, glass tanks, regenerators, tunnel kilns, evaporators, water coolers, cold-storage rooms, refrigerators, frozen-food lockers, and many other types of equipment.

The Bureau of Mines is not at liberty to publish annual production figures for diatomite, but total sales for 3-year periods may be shown.

The following table shows sales for such periods. Based upon returns received by the Bureau of Mines for 1942, about one-fourth of the total sales were for various insulation uses.

Sales of diatomite for 3-year periods, 1927-41

Year	Short tons	Value	Year	Short tons	Value
1927-29	286,426	$4,164,721	1936-38	279,645	$4,377,353
1930-32	248,273	3,902,126	1939-41	360,502	5,746,216
1933-35	244,342	3,618,428			

OTHER INSULATING MATERIALS

Certain chemicals when added to calcined gypsum react with mixing water and liberate gas, which expands the mass to a light porous body having fair insulating qualities. Such expanded gypsum is used chiefly for home insulation, but it may be used for insulating flat or slightly curved surfaces in industrial plants. The lightest product made weighs about 8 pounds per cubic foot. It can be used only for low-temperature insulation, because it begins to calcine, with consequent disintegration, at about 250° F.

Pumice, a cellular, glassy, volcanic rock light enough to float on water, has a structure that makes it a suitable heat-insulating material, but no production for insulating purposes in the United States has been recorded. The small quantities of lump pumice sold are used primarily as abrasives.

Pumicite, sometimes called volcanic ash, originates from viscous lavas blown with explosive force from volcanoes, in which large quantities of gas are generated. It resembles fine glassy sand or crushed glass. The larger grains, like pumice, may possess a certain degree of porosity, but expansion of the included gases has generally so shattered the grains that the resulting dust possesses little included air. It has some merit as an insulator, but, according to records of the Bureau of Mines, not more than 600 tons annually have been sold for insulating uses during recent years. These uses include steam- and water-pipe insulation, boiler lagging, and linings for cold-storage rooms.

A new product known as silica aerogel appears to have promising possibilities as an insulator. Its manufacture is based upon the principle that if silica gel is heated under sufficient pressure to prevent evaporation within the gel, no gas phase forms until the critical temperature of the liquid is reached. At this point the liquid phase is converted to the gaseous phase instantaneously, thus avoiding a gas-liquid interface. Under these conditions the gas may be withdrawn without causing collapse of the solid structure. The resulting product is a light, friable, siliceous, opalescent solid containing as much as 95 percent air space by volume. It is said to have a density as low as 1.8 pounds per cubic foot. It was first applied where extreme differences in temperature exist, such as in high-temperature laboratory furnaces and extremely low-temperature freezing chambers. It has passed little beyond experimental stages, but extensive application to many uses is forecast.

A recently developed product to which the trade name "foamglas" has been applied consists of glass blocks containing innumerable tiny sealed air chambers. The raw material is ground cullet to which about 1 percent carbon has been added. Gas is generated withing the mass during fusion. It has a weight of about 10 pounds per cubic foot. Its thermal conductivity is 0.45 at 70° F. and 0.70 at 300° F. It is especially applicable to low-temperature insulation where resistance to water absorption is a vital factor, but it may be used for insulating high-temperature equipment up to 1,000° F.

Lightweight concretes are used primarily in building construction but have certain industrial insulation uses. They are made in various ways. Some are compounded like ordinary concrete, except that lightweight aggregates are used. Others involve the use of foaming agents that create a porous structure. One use that might be classed as industrial is for making heat-insulating walls in airplane or other factories.

A lightweight concrete in which haydite, an expanded clay product, is used as aggregate, has been applied to several industrial insulation uses. A concrete of this type weighing 80 pounds per cubic foot has a thermal conductivity of 2.5 at 75° F., and if high-alumina cement is employed it may be used where temperatures are as high as 2,000° F. If the haydite is replaced in part with expanded vermiculite, the heat conductivity and weight per cubic foot are reduced with minimum loss of strength. Haydite concretes have been employed for high-temperature insulation, for furnace coverings, and as baffles in boilers, oil-distillation equipment, Cottrell dust precipitators, and industrial stacks.

Lightweight aggregates may be used alone as low-conductivity fillers.

Porous fire brick are used extensively for high-temperature heat insulation, particularly as a backing for refractory furnace linings. Such bricks are usually made by adding an inflammable constituent such as sawdust, which burns out during calcination, leaving a porous structure. Ordinary fire brick may afford a fair degree of thermal insulation.